Improvement in Error Performance by Cooperation

Kamel Tourki, Luc Deneire

Improvement in Error Performance by Cooperation

Kamel Tourki and Luc Deneire

***Abstract*— For mobile users without antenna arrays, transmission diversity can be achieved with cooperative transmissions, or by multi-branch system which uses the relays reached by the transmitter. When there is only one relay that can be reached by the transmitter, the transmission diversity can be obtained by a multi-hop system, then we emulate the (2 transmit antennas, 2 receive antennas) cooperative diversity scheme. This approach successfully deals with the problem of just one receiving antenna in a handset. Simulation results indicate an improvement in error performance over the simple (2,1) Alamouti (coded) or relaying scheme.**

I. INTRODUCTION

Multiple antennas at the receiver and the transmitter are often used to combat the effects of fading in wireless communication system. However, implementing multiple antennas at the mobile stations is impractical for most wireless applications due to the limited size of the mobile unit. So, active users pool their resources to form a virtual antenna array (VAA) that realizes spatial diversity gain in a distributed fashion [2]. It is the cooperative diversity (CD) system.

The concept of VAA mainly bases on relaying with a clever synchronization and encoding technique. Benefits of relaying include extension of high data coverage, reduction of transmitting power, overcoming dead-spots and ad-hoc networks. Relaying can be used to combat the difficulties of high data rate transmission over large distances. The idea of relaying was used for the concept of Opportunity Driven Multiple Access (ODMA), which was one of the proposals for UMTS Terrestrial Radio Access (UTRA). The main idea was to use mobile stations (MSs) as repeaters (Amplify and Forward), which is depicted in Fig. 1.

Another situation, where a VAA is embedded into a $3G$ communication system. Here, the direct link between base station (BS) and mobile terminals (MTs) is based on $3G\ UMTS\ W-CDMA$. For the relaying link, a current standard with direct mode communication capabilities is required, which is chosen to be Bluetooth. Therefore, MTs which happen to be in communication range of the Bluetooth tranceiver form a VAA in the sense that they start supporting each other via mutual communication. They continue communicating with the BS using the $W-CDMA$ link and, at the same time, relay further captured information, after decoding and Forwarding it, to the other MTs within the VAA group using Bluetooth, thereby increasing the end-to-end link capacity. Cooperative transmission (without STBC) has been proposed in cellular networks for cooperative diversity [5] and in sensor networks for energy efficiency and fault tolerance [6]. The rest of the paper is organized as follows. Starting with general cooperative links, in which we present the uncoded and coded transmission cases, section II lays out the simulation results, and section III concludes the paper.

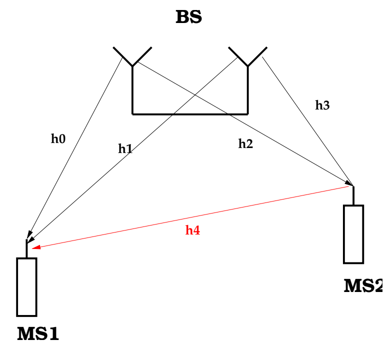

Fig. 1. 2 BS antennas and 1 relaying MS emulating the (2,2) Alamouti scheme

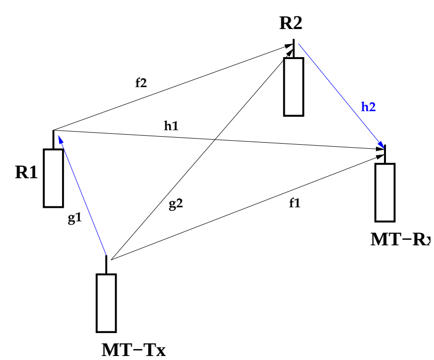

Fig. 2. Cooperative network scheme, the terminals R_1 and R_2 cooperate with the undergoing transmission between $MT-Tx$ and $MT-Rx$

II. GENERAL COOPERATIVE LINKS

A. Uncoded Transmission for VAA

1) System Model: Consider the CD strategy shown in Fig. 2, where we have an information source, $MT-Tx$, and a destination, $MT-Rx$, communicating over a channel with fading coefficient f_1. The relay terminal $R1$ communicating with $MT-Tx$, is willing to participate in the link providing $MT-Rx$ with a second copy of the original signal through the complex channels $MT-Tx \rightarrowtail R1$ and $R1 \rightarrowtail MT-Rx$, with flat fading coefficients g_1 and h_1 respectively. Without loss of generality, we assume that the additive white gaussian noise (AWGN) terms, n, n_{R_1}, and n' have equal variance

K. Tourki is a PhD student in image and signal processing at the University of Nice Sophia Antipolis, I3S Laboratory , France tourki@i3s.unice.fr

L. Deneire is an Assistant Professor, IUT Nice Sophia Antipolis, I3S Laboratory, France deneire@i3s.unice.fr

N_0. Similar to [3], [5], we propose that the realizations of the random variables f_1, g_1 and h_1 have been acquired at the receiver ends e.g., via training. Note that no particular assumptions are made on channel statistics.

We consider the Amplify and Forward $(A\&F)$ model where relays simply amplify the signal received from the source [3]. Assuming that $MT-Tx$ and $R1$ transmit through orthogonal channels, the destination $MT-Rx$ receives two independent copies of the signal x, transmitted by the source.

$$\begin{aligned} y_D &= f_1 x + n \\ y_{R_1} &= h_1 A_1 (g_1 x + n_{R_1}) + n' = h_1 A_1 g_1 x + N \end{aligned} \tag{1}$$

Where $N = h_1 A_1 n_{R_1} + n'$, and A_1 is the amplification factor which will be discussed later.

The receiver collects these copies with a maximum ratio combiner (MRC). We emphasize that the noise terms n and N do not have identical power because N includes a noise contribution at the intermediate stage; for this reason, the MRC should be preceded by a noise normalization step. With this combining rule, we form a decision variable z by weighting the combination with the respective powers. The resulting SNR of the decision variable is,

$$\gamma_z = |f_1|^2 \frac{P_x}{N_0} + |A_1 g_1 h_1|^2 \frac{P_x}{N_0} = \gamma_D + \gamma_{R_1} \tag{2}$$

Where P_x is the transmitted power at $MT-Tx$, $\gamma_D = |f_1|^2 \frac{P_x}{N_0}$ and $\gamma_{R_1} = |A_1 g_1 h_1|^2 \frac{P_x}{\sigma_R^2}$.

The term γ_D in (2) is the per-hop SNR associated with the direct channel f_1; that is, $\gamma_D = \gamma_{f_1} = |f_1|^2 \frac{P_x}{N_0}$, but the term γ_R requires a bit more elaboration. Expanding n_R, the term γ_R takes the form :

$$\gamma_{R_1} = |A_1 g_1 h_1|^2 \frac{P_x}{\left(1 + |A_1 h_1|^2\right) N_0} \tag{3}$$

Here we have choices over the amplification factor A_1; a convenient one maintains constant average power output, equal to the original transmitted power [4].

$$A_1^2 = \frac{P_x}{P_x |g_1|^2 + N_0} \tag{4}$$

Substituting (4) into (3) and (2) we obtain,

$$\gamma_z = \frac{\gamma_g \gamma_h}{1 + \gamma_g + \gamma_h} + \gamma_f \tag{5}$$

Where γ_g and γ_h are the per-hop SNRs associated with the channels g_1 and h_1, respectively, and are defined similarly to γ_f; that is $\gamma_g = |g_1|^2 \frac{P_x}{N_0}$ and $\gamma_h = |h_1|^2 \frac{P_x}{N_0}$.

At high SNR, (5) reduces to :

$$\gamma_z = \frac{\gamma_g \gamma_h}{\gamma_g + \gamma_h} + \gamma_f \tag{6}$$

Which is equivalent to considering an amplification factor $A_1 = \frac{1}{g_1}$. Similarly, we have another cooperating branches, via $R2$ and $\{R1, R2\}$, then we derive:

$$y_{R_2} = h_2 A_2 (g_2 x + n_{R_2}) + n''. \tag{7}$$

Where $A_2^2 = \frac{P_x}{P_x |g_2|^2 + N_0}$ is an amplification factor, and n_{R_2} and n'' are the noise terms.

$$y_{R_1,R_2} = h_2 A_2' \left(f_2 A_1' (g_1 x + n_1) + n_2 \right) + n_3 \tag{8}$$

Where $A_1' = \frac{1}{g_1}$ and $A_2' = \frac{1}{g_2}$ are the amplification factors, and n_1, n_2, and n_3 are the noise terms. We have

$$\gamma_{R_2} = |A_2 g_2 h_2|^2 \frac{P_x}{\left(1 + |A_2 h_2|^2\right) N_0} = \gamma_{R_1} \tag{9}$$

$$\gamma_{R_1,R_2} = \frac{|h_2 f_2 A_1' A_2' g_1|^2 P_x}{\left(1 + |A_2' h_2|^2 + |A_2' h_2 A_1' f_2|^2\right) N_0} \tag{10}$$

In four receiver-branches case, $\{MT-Tx, R1\} \rightarrowtail \{R2, MT-Rx\}$, the resulting SNR of the decision variable is

$$\gamma_z = \gamma_D + \gamma_{R_1} + \gamma_{R_2} + \gamma_{R_1,R_2} \tag{11}$$

Since the relaying $R1$ and $R2$ introduce additional noise and the relaying channels are double-Rayleigh or triple-Rayleigh, the scheme is expected to operate below a diversity gain of four.

B. STBC for VAA

As for the schemes proposed by Alamouti in [1], we consider a wireless communicating system with two transmit antennas at the BS. The path gains are modelled as samples of independent complex Gaussian random variables. The real part and imaginary part of the path gain have zero mean and equal variance of 0.5. We also assume that fading is constant across two consecutive symbols. Receiver noise and interference are represented by complex random variables. They are mathematically modelled by two independent zero-mean Gaussian random variables with variance $(2SNR)^{-1}$ per complex dimension since the average power of the transmitted symbols is normalized to unity.

$$\begin{aligned} r_0 &= r(t) = h_0 s_0 + h_1 s_1 + n_0 \\ r_1 &= r(t+T) = -h_0 s_1^* + h_1 s_0^* + n_1 \end{aligned} \tag{12}$$

Where T is the symbol duration, r_0 and r_1 are the received symbols at t and $t+T$, and n_0 and n_1 are the complex random variables representing receiver noise and interference.

The main idea is to use another (supporting) MS as a transparent relay. This latter one acts as a second receiving antenna for the target MS. The scheme is depicted in Fig. 1. The idea is to send both orthogonal streams intended for the target $MS1$ from two transmit antennas at the BS. Both these streams are received by the relaying $MS2$ and the target $MS1$, through different channels h_0, h_1, h_2 and h_3. The relaying $MS2$ retransmits, after amplifying or decoding, its received double stream to the target $MS1$, acting as a transparent transceiver.

Since the two signal streams are considered separable, the combining takes place in the target $MS1$ as suggested by Alamouti. As for the $(2,2)$ Alamouti scheme, the target receives

$$\begin{aligned} r_0 &= h_0 s_0 + h_1 s_1 + n_0 \\ r_1 &= -h_0 s_1^* + h_1 s_0^* + n_1 \end{aligned} \tag{13}$$

And the relaying $MS2$ receives

$$\begin{aligned} r_2 &= h_2 s_0 + h_3 s_1 + n_2 \\ r_3 &= -h_2 s_1^* + h_3 s_0^* + n_3 \end{aligned} \tag{14}$$

After amplification $(A\&F)$ or decoding $(D\&F)$, which is set to unity due to the preformed channel and signal normalization, the relaying $MS2$ retransmits the received double stream through channel h_4. Then the target $MS1$ receives finally :

$$\begin{aligned} r_4 &= h_4 r_2 + n_4 \\ r_5 &= h_4 r_3 + n_5 \end{aligned} \tag{15}$$

We define H_0 and H_1 as :

$$\begin{aligned} H_0 &= h_4 h_2 \\ H_1 &= h_4 h_3 \end{aligned} \tag{16}$$

Then

$$\begin{aligned} r_4 &= H_0 s_0 + H_1 s_1 + N_0 \\ r_5 &= -H_0 s_1^* + H_1 s_0^* + N_1 \end{aligned} \tag{17}$$

Where

$$\begin{aligned} N_0 &= h_4 n_2 + n_4 \\ N_1 &= h_4 n_3 + n_5 \end{aligned} \tag{18}$$

Since the two double streams are separable, the combining for each path takes place independently. Traditional channel estimation is performed for the relaying stream since the receiver does not know about the relay a priori. The combiner then builds the following estimated signals for the direct link.

$$\begin{aligned} \widetilde{s}_0 &= h_0^* r_0 + h_1 r_1^* = \left(\alpha_0^2 + \alpha_1^2\right) s_0 + h_0^* n_0 + h_1 n_1^* \\ \widetilde{s}_1 &= h_1^* r_0 - h_0 r_1^* = \left(\alpha_0^2 + \alpha_1^2\right) s_1 + h_1^* n_0 - h_0 n_1^* \end{aligned} \tag{19}$$

And the relaying link :

$$\begin{aligned} \widetilde{s}_0 &= H_0^* r_4 + H_1 r_5^* = \left(\alpha_2^2 \alpha_4^2 + \alpha_3^2 \alpha_4^2\right) s_0 + H_0^* N_0 + H_1 N_1^* \\ \widetilde{s}_1 &= H_1^* r_4 - H_0 r_5^* = \left(\alpha_2^2 \alpha_4^2 + \alpha_3^2 \alpha_4^2\right) s_1 + H_1^* N_0 - H_0 N_1^* \end{aligned} \tag{20}$$

Where α_0, α_1, α_2 and α_3 are the Rayleigh distributed envelopes of the channels from the two base station antenna elements to the target and relay mobile, respectively, and α_4 represents the relaying channel.

The estimations of the two symbols are then summed. Since the relaying $MS2$ introduces additional noise and the relaying channel is double-Rayleigh, the scheme is expected to operate below a diversity gain of four.

III. Simulations

All schemes were simulated assuming BPSK modulation. It is also assumed that the amplitudes of the fading from each transmit antenna to each receive antenna are uncorrelated and Rayleigh distributed. Furthermore, we assumed that all receivers have the same noise properties. This implies that in Fig. 1 and Fig. 2 the noise power of all $receiver-branches$ is the same. Further, we assumed that the receiver has perfect knowledge of the channels.

Under these assumptions, the simulations provide reference performance curves for comparison with known techniques. Fig. 4 depicts the reference curves of the $(2,1)$ and $(2,2)$ Alamouti scheme.

The VAA scheme with applied STBC was simulated assuming perfect power control and prefect channel estimation. From Fig. 4 one can see that the emulated $(2,2)$ VAA scheme (A & F or D & F) performs worst than the traditional $(2,2)$ Alamouti scheme (green curve), however better than the $(2,1)$ Alamouti scheme (red curve). Therefore, at link level VAA proves to be superior over a non-VAA scheme. Finally, since it is difficult to implement a MS with more than one antenna, this technique provides better performance than known techniques using two transmit antennas and one receive antenna. The diversity order of the emulated $(2,2)$ VAA is three.

In fig. 2, the uncoded transmission scheme was simulated assuming perfect power control and prefect channel estimation. From Fig. 3 one can see that the emulated $(2,2)$ VAA scheme, performs better than the single relay cooperative system. The diversity order of the emulated $(2,2)$ cooperative system is three.

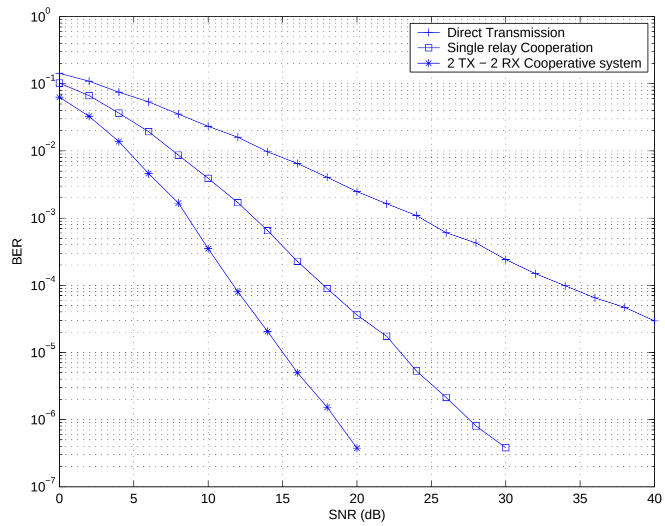

Fig. 3. uncoded multi-branch cooperative transmission

IV. Conclusions and Future Works

A. Conclusions

The Virtual Antenna Arrays was presented, which primarily targets to overcome the disadvantage of having only one or few antennas available in a mobile terminal. Adjacent mobile terminals form an ad-hoc VAA by means of a link between the antenna elements of each terminal.

B. Future Works

Unfortunately, it is difficult, and in most cases impossible, to achieve perfect synchronization among distributed transmitters. Therefore a challenge is the lack of perfect synchronization on delay and mobility of distributed transmitters. Considering both imperfect delay synchronization and frequency selective fading, is similar to considering dispersive channels. Although contributions on the topic of the asynchronous cooperative diversity have begun to emerge,[7] and [8], the amount of work done is scarce in comparison to the vast amount of potential scenarios.

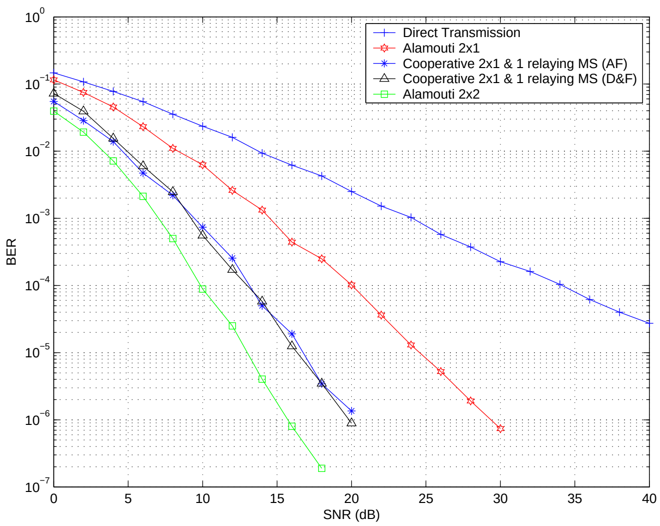

Fig. 4. BER performance of 2 BS antennas and 1 relaying MS emulating the (2,2) Alamouti scheme with perfect power control in the relaying link

REFERENCES

[1] Siavash M.Alamouti, ”A Simple Transmit Diversity Technique for Wireless Communications”, *IEEE JOURNAL ON SELECT AREAS IN COMMUNICATIONS*, VOL. 16, NO. 8, October 1998.

[2] Misha Dohler, ”Virtual Antenna Arrays”, *PhD Thesis*, University of London, November 2003.

[3] J. N. Laneman, ”Cooperative diversity in wireless networks: algorithms and architectures”, *PhD Thesis*, Massachusets Institute of Technology, September 2002.

[4] J. N. Laneman and G. W. Wornell, ”Energy-efficient antenna sharing and relaying for wireless networks”, in *proc. of Wireless Communications and Networking Conference*, vol. 1, pp. 7-12, Chicago, Illinois, September 2000.

[5] A. Sendonaris, E. Erkip and B. Aazhang, ”User cooperation diversity, Part I, II”, *IEEE Trans. Comm.*, Vol. 51, no. 11, pp. 1927-1948, Nov 2003.

[6] X. Li and N. E. Wu, ”Power efficient wireless sensor networks with distributed transmission-induced space spreading”, *Proc. 37th Asil. Conf. Signals, Syst., Comput.*, Pacific Grove, CA, Nov 2003.

[7] X. Li, ”Space-Time Coded Muli-Transmission Among Distributed Transmitters Without Perfect Synchronization”, *IEEE Signal Processing Letters*, Vol. 11, no. 12, pp. 948-951, Dec. 2004.

[8] K. Tourki and L. Deneire, ”Precoding and Distributed STBC for Asynchronous Cooperative Diversity”, *International Wireless Summit; Wireless Personal Multimedia Communications*, Aalborg, Denmark, September 2005.